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Persistence of insecticides in the soil

Five years after a farmer has applied a dose of DDT, a third or more of it may remain in the soil. Other pesticides disappear more rapidly, but they may still affect plants and mammals or upset the natural balance of soil animals—though not necessarily more than other agricultural practices

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A mixed group of soil animals that are affected by insecticides.

THE recent development and use of a large number of pesticides has resulted in bigger and better crops. Carrots with rusty lesions caused by carrot fly or potatoes with holes made by cutworms, wireworms or slugs no longer find a ready market.

Unfortunately, chemicals that kill insects and other pests may also kill vertebrates, and although there is a constant search for specific pesticides which are harmless to other organisms, no chemical so far developed completely fulfils these requirements. During the past two years the public has become concerned about the possibility of danger from the widespread use of chemicals that could accumulate in tissue and become harmful to plants and animals on agricultural land, but much that has been said on this subject is speculative, with little or no scientific evidence to support it.

Many of the pesticides that are used in agriculture or horticulture are foliage sprays which, although relatively toxic to vertebrates, decompose quickly and leave no harmful residues in plants and the soil. The main risk in using such materials, particularly the organophosphates, is to the person applying them, that is if he does not take reasonable precautions. Paradoxically, it is chemicals such as the chlorinated hydrocarbons which, with few exceptions, are not very toxic to vertebrates, that are potentially the most dangerous. This is because they are very persistent and can accumulate in vertebrate tissues, thus raising long-term problems. Chlorinated hydrocarbons, particularly DDT, aldrin and dieldrin, have been widely used, especially as soil insecticides, in the United States, and are being used increasingly in Britain. These chemicals—used as seed dressings to control wheat bulb fly—were those alleged to have killed many wild birds in 1961 and 1962, and there is now a government ban on their use in the treatment of spring-sown wheat.

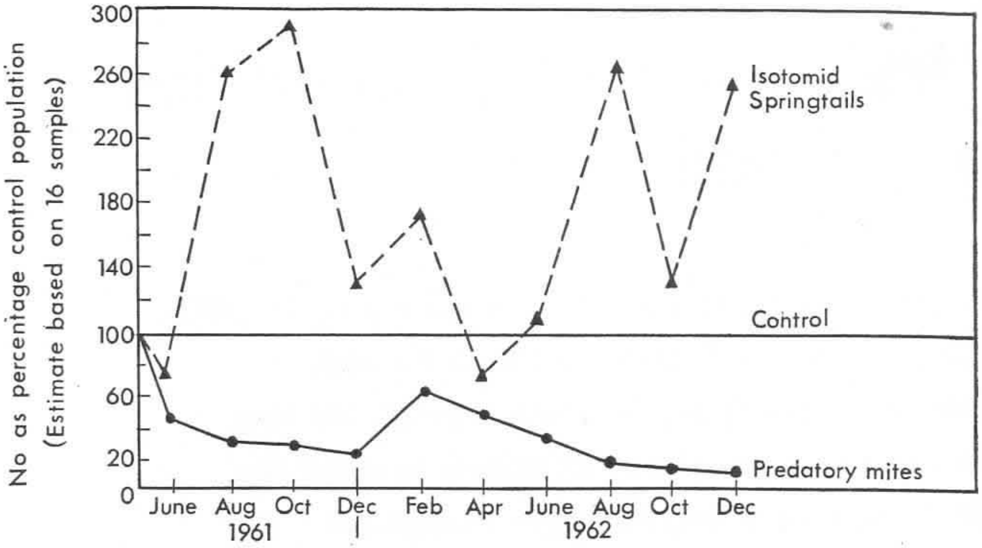
How do insecticide residues get into soil?—When insecticides are applied to foliage, some of the chemical inevitably falls on to the soil around the plants, in quantities that depend both on the efficiency with which they are applied and on the crop being treated. High volume sprays, using about 100 gal of water per acre, probably get more of the chemical to its target than low volume sprays, dusts, smokes or aerosols, all of which produce more drift. However, even with high volume sprays, only about 50 per cent of the sprayed chemical reaches the plant, and some of this may later be washed off on to the soil. Fortunately even persistent insecticides, that fall on to the soil, break down relatively rapidly, possibly ten times faster than when they are incorporated into the soil.

A much more important source of soil insecticide residues than foliage sprays, are the chemicals used to control soil-in-

habiting pests. These may be applied to the soil as surface sprays or dusts and later cultivated in, combined and distributed with fertilizer, or coated on to the seed before sowing. The insecticide most commonly used is aldrin, which has now almost completely replaced gamma-BHC for control of soil pests in Britain. This and other soil insecticides, and the amounts normally used for a single application, are given in Table I.

Insecticides	Active ingredient, lb per acre
DDT	1—2½ (10)
BHC	1—2½ (5)
Aldrin	1—3 (6)
Dieldrin	1—3
Heptachlor	1—3
Chlordane	1—2 (6)
Toxaphene	1—2
Telodrin	¼—1

TABLE I. *Range of single doses usual with soil insecticides (dosages in brackets may sometimes be needed against certain pests).*



The effects of soil applications of DDT on the predatory mites and springtails. The reductions in numbers of mites are reflected by increases in numbers of springtails.

DDT is the most persistent of these chemicals and then, in order of decreasing persistence, come toxaphene, lindane, chlordane, heptachlor, dieldrin and aldrin. As much as 35 per cent of DDT applied may still be present after five years whereas aldrin may fall to 25 per cent of the amount applied in one year—although another 25 per cent may have been broken down into dieldrin. The rates of breakdown are such that, if amounts of the order given in Table I were applied annually most of the insecticides would accumulate in treated soil.

We have very little information about the amounts of insecticide residues actually present in farm and horticultural soils in the United Kingdom. Recently 21 potato fields were surveyed in southern England, and DDT residues were found in 14, aldrin in 9 and dieldrin in 17. The largest residue of aldrin was about 0.3 lb of active ingredient per acre, 1.0 lb per acre of dieldrin and 2.0 lb per acre of DDT. There are no figures for residues in orchard soils but, in the United States, amounts of DDT ranging from 1.5 lb to 176 lb per acre have been found in surveys, and since as much as 10 lb of DDT per acre may be applied annually to fruit trees in British orchards, probably many of the orchards have contaminated soils.

How difficult is it to analyse soil insecticide residues?—Fuller information about the amounts of these chemicals in soil depends on rapid and specific methods of analysis. Many of the specific analytical methods used have been complicated and laborious, involving very thorough field sampling, extraction of the chemical from the soil, separation of the residues from materials that might contaminate the extract ("clean up") and finally the actual analysis. Alternatively, bio-assays, using living organisms to estimate amounts of toxic materials, have been used, but these are laborious, time-consuming and non-specific.

More recently, the powerful analytical technique called two-dimensional paper chromatography has been used to give good and comparatively rapid estimates of amounts of chlorinated hydrocarbons in soil, and has the advantage that several different insecticides can be estimated during a single analysis. Finally, with the refinement of gas-liquid partition chromatography analysis for soil residues, we have a much more sensitive technique for rapid and sensitive determinations, so that now it should not be long before we have more detailed and reliable information on the amounts of residues in soils.

Can residues persist indefinitely? — Because they become adsorbed on to organic matter, the type of soil into which the insecticides are incorporated is one of the most important factors affecting their persistence. Adsorption reduces their effectiveness as insecticides; it also makes them persist much longer. Thus a fen soil with 40-50 per cent organic matter requires much more insecticide to kill pests that live in it, than a mineral soil with only 2-3 per cent of organic matter, and the residues remain in it much longer.

The life of insecticidal residues is also very much influenced by moisture and temperature; chemicals disappear much faster from a wet soil than from a dry one, and from a warm soil than a cold one. Cultivation can affect the time insecticides remain in soil and, in one experiment when soil was disked twice a week for three months, aldrin and DDT residues fell by one third more than in undisturbed soil. The ways in which insecticides are broken down are not yet clear, but certainly some volatilise or are decomposed by bacteria. The breakdown products may be more or less active as insecticides than the original insecticide; thus, for example, aldrin becomes oxidised into dieldrin whereas lindane changes into non-insecticidal chemicals that can, however, still taint crops. Most chlorinated hydrocarbons break down rapidly at first, but traces remain for many years. All attempts made so far to remove residues completely from soil have failed.

Ecological importance of soil insecticide residues.—Chemicals in the soil are bound to change the flora and fauna, and if they persist for long enough these changes may be lasting. But most of the operations involved in growing an agricultural crop also create changes, and the problem is whether the changes caused by insecticide residues are such that the use of insecticides is not justified. The soil microflora and fauna and the growing crops may all be influenced by chemicals in the soil, either beneficially or harmfully.

There are many technical difficulties in determining whether numbers of soil *micro-organisms* have increased or decreased, but all the existing evidence shows that they are not seriously affected except by excessive amounts of insecticide, which may inhibit some and stimulate others. Certainly the growth of *plants* can be affected by large dosages of insecticides in soil, but it seems unlikely that the current residues in agricultural land in Britain are large enough to harm crops. Of the soil insecticides, lindane has the greatest effect on plants, especially to cereals; it can also taint root crops in amounts as small as ½ lb of active ingredient per acre. Its place as a general soil insecticide has now largely been taken by aldrin, which is

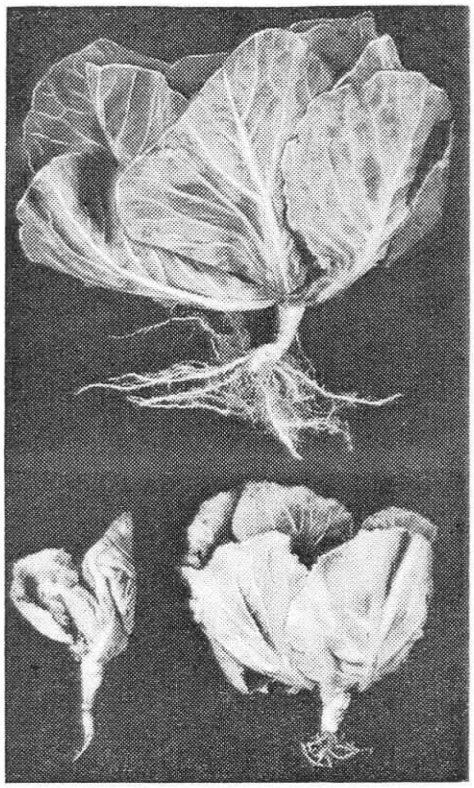
much less likely to harm plants, although it can affect the growth of cucumbers, tomatoes, beet, beans and cereals grown in soil containing more than 15 lb of active ingredient per acre; aldrin in smaller amounts can also change the flavour of root crops. DDT is not much used as a soil insecticide and reaches the soil mainly from spray fall-out; it is even less harmful to plants than aldrin, but dosages above 15 lb per acre may affect the growth of beans, tomatoes, cucumbers and especially legumes. In some experiments the growth of carrots and parsnips has been stimulated by large amounts of DDT in the soil. Chlordane, heptachlor and toxaphene are sometimes used in soil, but have not harmed crops, even at the largest dosages tested.

Another possible hazard in the use of soil insecticides is that they are taken up into plants and thence into the tissues of the animals that eat them. There is evidence that small quantities of chlorinated hydrocarbons can enter and move through many kinds of plants, and root crops can absorb measurable amounts from soil containing large quantities of chemicals. The quantities taken up are very small and a large proportion of the amount in the crop would have to be retained in the tissues of a consumer to present a hazard. Nevertheless, the use of carrots grown in aldrin-treated soil as baby food may be an undesirable practice.

Unless they actually live in the soil, the *larger animals* are usually affected only by residues contained in their food, for instance insects that have been killed by insecticides. Fish are very sensitive to DDT and can be killed when water drains into streams and ponds from treated soil, but DDT is very insoluble and does not readily leach away. As already mentioned, birds may be killed by feeding on seed treated with insecticide, or insects killed by insecticide, and the residues can be passed on down a food chain when insectivorous birds are in turn eaten by predators such as eagles or foxes.

Insecticides are applied to soil to kill pests, so it is not surprising that their biological effects are greatest on the complex of *small animals* that occur in all soils. The arthropods are the ones that are principally affected; numbers of the other common soil animals such as earthworms, enchytraeid worms (potworms) and nematodes are unchanged by BHC, DDT, aldrin or dieldrin, even at large concentrations.

The most common of the numerous small soil arthropods are the springtails (Collembola) and the mites (Acarina), many of which may be important in the early stages of the breakdown of plant material that finds its way into the soil. Many species of springtails are not killed by DDT, but it does kill the mites that prey on them: consequently numbers of springtails almost always increase when DDT is used in soil. On the other hand aldrin kills the springtails, but does not affect the mites that prey on them, so that aldrin-treated soils usually have few springtails. In experiments, discs cut from leaves, and buried in soil from which earthworms were excluded, disappeared much more rapidly in soil treated with DDT than in untreated or aldrin-treated soil. When earthworms could attack the leaf discs, insecticides had much less effect on breakdown rates, and because most agricultural soils probably have adequate numbers of earthworms, the changes in numbers of springtails and other arthropods may not be very important. These small animals may have a function in soil formation and aeration but there is no evidence on how changes in their numbers may affect these processes.



*The benefits that soil insecticides can give. The bottom cabbages were grown in untreated soil, and attacked by cabbage root fly (*Erioischia brassicae *Bouche). The one above was grown in soil treated with aldrin.*

Of the other soil arthropods, beetles (adults and larvae), fly larvae, symphylids, pauropods, centipedes and millipedes are all killed by treating soil with either aldrin or DDT. These animals may be either pests or harmless animals or predators of pests. When the arthropods killed are pests, then the insecticide achieves its objective, but if they are predators of a pest not killed by the insecticide, the numbers of the pest may actually increase. For instance, dieldrin kills cabbage root fly larvae, but small dosages of about 1 lb per acre of active ingredient of this insecticide do not kill the larvae, but may kill beetles which prey on the eggs and larvae, leading to a more severe attack of root fly than would otherwise have occurred. A previously harmless arthropod may become a pest if it is unaffected by the insecticide which kills off its predators; this is probably how red spider became a serious pest of fruit.

One of the most distinct changes that occur when insecticides are applied to soil is a simplification of the species complex of small soil animals, so that only a few very numerous species remain. This is a typical effect of most agricultural operations on the natural flora and fauna, because the usual aim is the replacement of the complex indigenous vegetation by a single cultivated crop. The cultivation and change in flora has in turn large effects on the soil animals, favouring those species not damaged by cultivating the soil, those that are pests of the crop and those that prey on the pests. The only real difference between these effects and those due to the persistent insecticides are that the latter are more lasting.

An unfortunate feature of the use of soil insecticides is that they are often used unnecessarily or without sufficient consideration. Many farmers use an insecticide to control a serious pest and obtain such good results that they continue to use it as an insurance even when the pest is no longer serious. For instance, it has been estimated that since 1954 about 21 per cent of the ware potato crop has been treated with aldrin although only some 6 per cent showed signs of damage. In the future, until alternatives are found for the current chlorinated hydrocarbon insecticides, the chemicals must be used with consideration for residue accumulations. Where possible, local treatments or seed-dressings are preferable to the treatment of large areas, but where it is necessary to treat whole fields, the dose given should be decided on the basis of what chemicals are likely to have remained in the soil from previous treatments. Thereafter, the land should be "topped up" to an efficient insecticidal level and not given the amount recommended for a first dressing.

The increases in yields usually obtained by the use of soil insecticides indicate that their effects on pest predators, in damaging plants or on soil fertility are probably not serious. There certainly seems to be too little evidence to justify abandoning the chlorinated hydrocarbons. However there is a great need for research into possible side effects of the use of persistent chemicals, and a search for new insecticides that are more specific in action and less toxic to other animals.